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PROJECT REPORT

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Design of a Solar Powered Intermittent Ammonia-Water Absorption Refrigeration System.

By

H.A. Sandford
S.K. Sharma
C. Ezekwe

OBJECTIVES

1. Design an intermittent absorption refrigeration system with no moving parts and with the following capabilities:

   (a) Make use of Ammonia-water solution as the working fluid.
   (b) Produce two pounds of ice in 1/2 hour
   (c) Powered soley by solar energy by making use of a flatplate collector.
   (d) To refrigerate medicine in rural areas.

2. Make the design of the components of the total system as simple as possible to simplify operation and to reduce maintenance so as to make it more suitable for use in rural areas.

3. Hence to establish that if it is possible to produce ice, then with more sophistication this system can be used commercially to preserve perishable agricultural produce and a possible replacement for commercial air conditioning in the future, where the cooling temperature need not be lower than $40^{o}F$.

INTRODUCTION

The non-oil producing developing countries of the world has been undergoing severe balance of payment problems and other economic hardships, ever since the forming of O.P.E.C. and the continuous rising of the prices of fossil fuels since 1973. Many of these countries have economies that are highly based on large consumption of fossil fuels and in some of these countries fossil fuels consitutes as much as ninety-nine percent of their industrial needs which is rather catastrophic. With present trends, countries in this predicament will continue to encounter even greater hardships until alternatives are found to replace fossil fuels or at least to supplement to a great extent a large percentage of their consumption at present. Oil importing countries of the world both developed and developing alike are therefore set with a massive task of reducing their dependence on fossil fuels to the greatest extent in the shortest possible time. On the other hand whereas the oil-producing countries are in a different situation, they too have realized that their fossil fuel reserves will last only for a relatively short time. This has lead them to think, and rightly so, that fossil fuel is today's "gold" and not an energy resource on which their development should be heavily dependent upon. Moreover some countries have come to the realization that fossil fuel is far too important to be used as fuel when it can be used for purposes such as fertilizers, clothing, medicine, etc., which is far more beneficial to the survival of mankind. For these and other reasons, most of the countries, whether oil-producing or non oil-producing, are looking for alternative sources of energy for satisfying their needs in one way or another, preferable in the area of renewable resources. Of all the possible renewable resources we have at present, the sun seems to be the most promising.

The sun provides an annual average energy (worldwide) of approximately 1150 $KWh/m^2/yr$ on a horizontal surface at its surface with a peak power of approximatel $1.0\ KW/m^2$ at sea level, with an annual number of sunshine hours ranging from 1600 to values greater than 3600. It is therefore no doubt that a vast amount of energy is available to us from the sun and all we need is fairly efficient devices for collecting this energy.

The best known method of utilizing solar energy is to transform it into the particular form of energy which is needed in the minimum number of steps to ensure greater efficiency. With this in mind, we have decided to demonstrate in this project the direct use of solar energy for refrigeration and air conditioning. This project involves the design and construction of a simple intermittent ammonia water absorption refrigeration system capable of producing two pounds of ice in a single charge. This system is designed to operate at a generation temperature of approximately 165^oF, powered by solar energy by making use of a flatplate collector which is designed to match the system.

It is our primary aim to demonstrate the potential of solar refrigeration system is capable of operating solely from solar insulatior and without the use of electricity. This would be capable of operating in remote areas of many countries which in most of the developing countries are areas where there is an abundance of sunshine and are usually the most agriculturally productive. The need for such a system can be even more greatly appreciated when one considers that millions of dollars are lost yearly in developing countries due to spoilage of food crops. Prevention of such spoilage could greatly improve the economies of such countries coupled with the fact that most famine in the world is not only due to the lack of food production but is greatly attributed to spoilage of much of the food they produce.

In this project we also wish to demonstrate that is we are capable of producing ice we can also use this same system with relatively greater ease to preserve food and medicine and to provide air conditioning since the temperature required for these purposes need not be lower than 40^oF. With greater sophistication this system can be used to replace the conventional energy consumption air conditioning monsters in urban areas thereby reducing electrical energy consumptior produced by expensive fossil fuels. In the area of cooling and refrigeration nature has been very fortunate to us in that the supply of the sun's energy and the demand for it are closely matched and this matching extends in many situations even to the variation within the day. With this help already available from nature it is to our benefit to capitalize on this.

THEORY

Absorption Refrigeration

The elimination of the necessity of large quantities of shaft work has been the prime reason for the success of various absorption refrigeration systems. The greatest disadvantage of a vapor-compression refrigeration system is that it requires the expenditure of expensive "high-grade" energy in the form of shaft work to drive the compressor. In the operation of the absorption system, the function of the compressor is replaced by a generator, an absorber, a small solution pump and a heat source. These systems function on the principle that many substances can attract and hold large quantities of vapor of other substanc at a relatively low pressure and temperature; these vapors can be regenerated when energy is added, thus raising the temperature and pressure of the solution.

In the absorption process, when the vapor goes into solution, the heat of chemical reaction or heat of solution must be removed. Practical combinations of refrigerant and absorbent require that large quantities of one can be easily absorbed into the other.

To illustrate the principle of operation of an intermittent absorption refrigeration system, a schematic diagram of such a system is shown in Figure 1. The advantage of the intermittent system over the continuous is that it requires fewer components. By incorporating the absorber and the generator into one vess and the evaporator and condenser into another reduces the cost of the system.

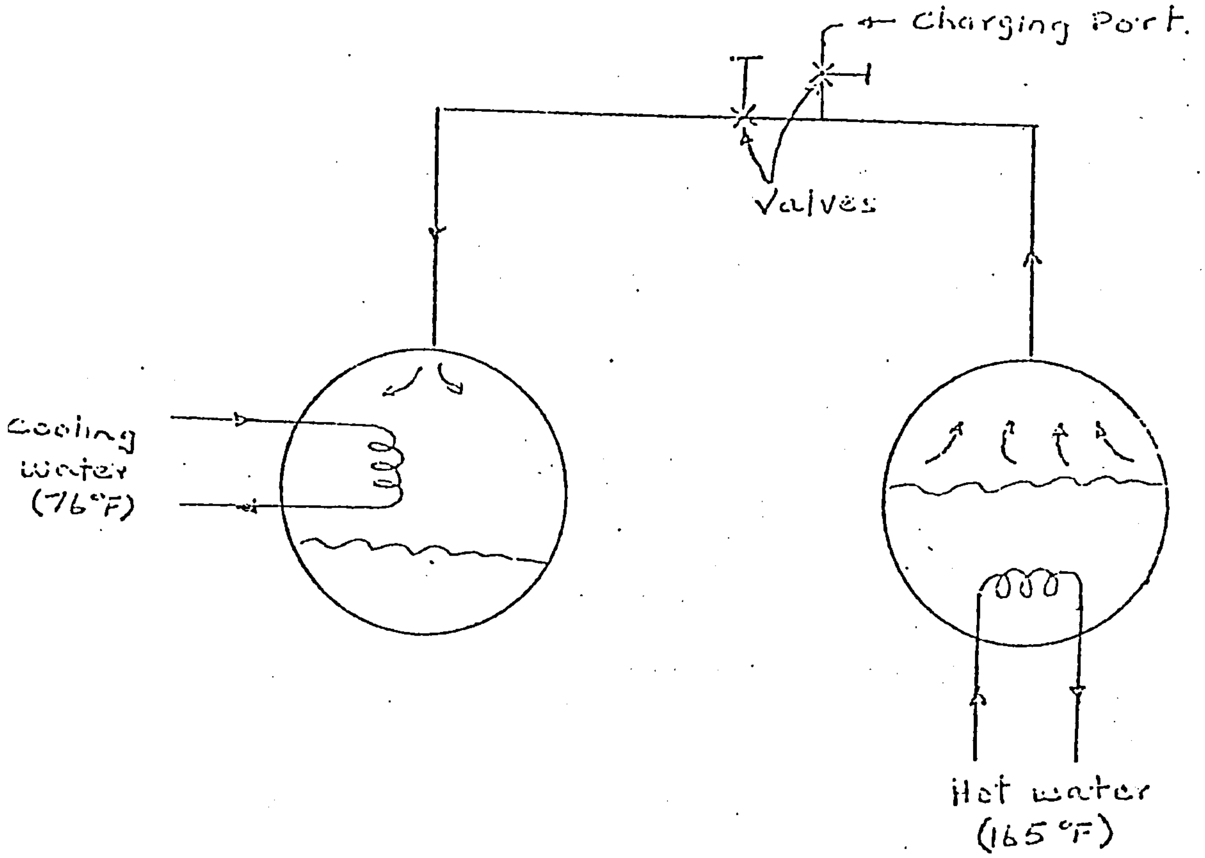
The cycle can be divided into two processes; one consisting of generation and condensation; the other of evaporation and absorption. During the generatio mode (the generation mode is composed of ammonia vapor generation in the generat and condensation of the ammonia vapor in the condensor), heat is supplied to a high concentration (strong) ammonia/water solution. The ammonia will vaporize preferentially and the resulting vapor will have a much higher proportion of ammonia than the original liquid solution. As a result, the concentration of ammonia in water will be reduced for the remaining liquid solution. As the ammonia is driven from the solution, the pressure in the system will rise until condensation of the vapor can be achieved in the condenser. Condensation will take place as long as the temperature of saturation of the ammonia at the corresponding system pressure is higher than the temperature of the heat sink medium (usually cooling water). As the liquid ammonia/water solution gets weaker (less concentrated), the vaporizing temperature of the liquid solution at the pressure required for condensation will rise, tending to approach the boiling point of water at the given pressure. Once the required amount of ammonia has been driven from the solution, the cooling mode (the cooling mode is composed of liquid ammonia vaporizing in the evaporator and ammonia vapor being absorbed into solution in the absorber) begins.

The achieve refrigeration, the weak ammonia/water solution in the generator is cooled. As the temperature of solution is lowered, the weak solution starts to absorb the ammonia vapor which was not condensed, resulting in a lowering of the system pressure. The equilibrium pressure during the cooling mode will depend on the concentration of the ammonia/water solution, that is, the weaker the solution the lower the pressure for a fixed heat sink or cooling water temperature. It also depends on the temperature of the ammonia/water solution (which depends on the cooling water temperature) for a fixed concentration, the lower the temperature of the solution, the lower the pressure. For this relatively low pressure (34 psig) the temperature of saturation of the ammonia (20 degrees Farenheit) in the evaporator is very low. At this point water at ambient temperature (76 degrees Fahrenheit) is poured around the evaporator. The ammonia will vaporize by extracting heat from the surrounding water, thus giving rise to the refrigerati effect. The ammonia vapor generated in the evaporation process is absorbed by the weak solution in the absorber-generator vessel. Enough surface contact between the ammonia vapor and the weak solution should be supplied in order to balance the system; that is, to absorb the vapor back into the solution at the same rate which it is evaporated in the evaporator. Failure to absorb the ammonia vapor at the same rate that it is evaporated in the evaporator will result in an increase in the system pressure, which will raise the boiling point of the ammonia in the evaporator, affecting the refrigerating effect. As the ammonia vapor is being absorbed the heat of solution (exothermic reaction) must be removed, otherwise the temperature of the ammonia/water solution will rise and consequently raise the pressure in the system. This increase in the pressure will also result in an increase of the vaporization temperature of the ammonia in the evaporator. Eventually this pressure will increase to the point at which the temperature of saturation for the ammonia will be in equilibrium with the ambient temperature. During the cooling mode as the ammonia is being absorbed, the concentration of the weak solution increases until it reaches the concentration of the initial, strong solution. At this point the generation mode is initiated and the cycle is repeated.

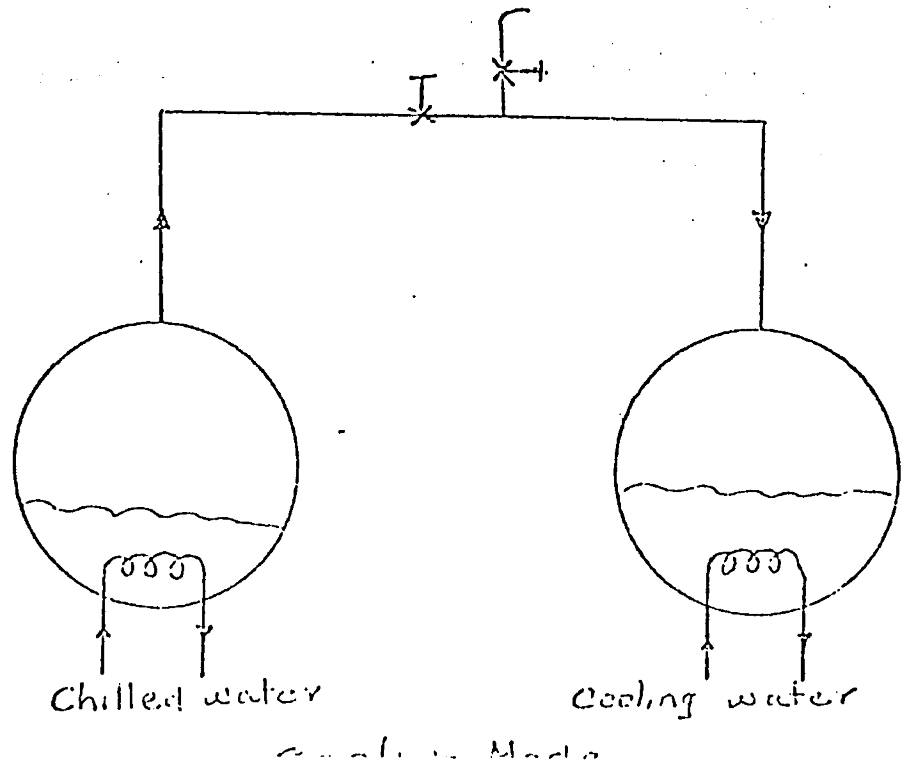
When designing intermittent ammonia/water absorption system, the concentatio of the strong solution and the weak solution are chosen depending on the temperature of the heat source, the temperature of the heat sink and the temperature at which the refrigeration effect is desired. Setting two of the above parameter automatically sets the other. Usually the two fixed parameters are the temperatu are the temperature of the heat sink and the temperature at which the cooling ef is desired; after these two parameters are known, the minimum temperature of the heat source required is established. However in our design that follows, the three operating temperatures were chosen and the system designed around them.

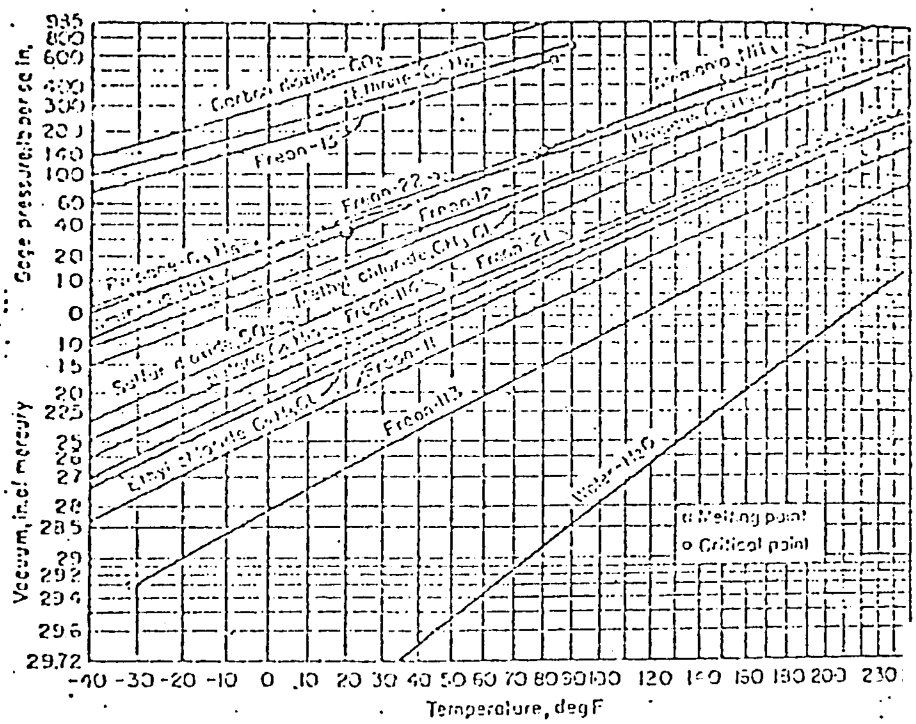
INTERMITTENT ABSORPTION REFRIGERATION SYSTEM

FIG 1.



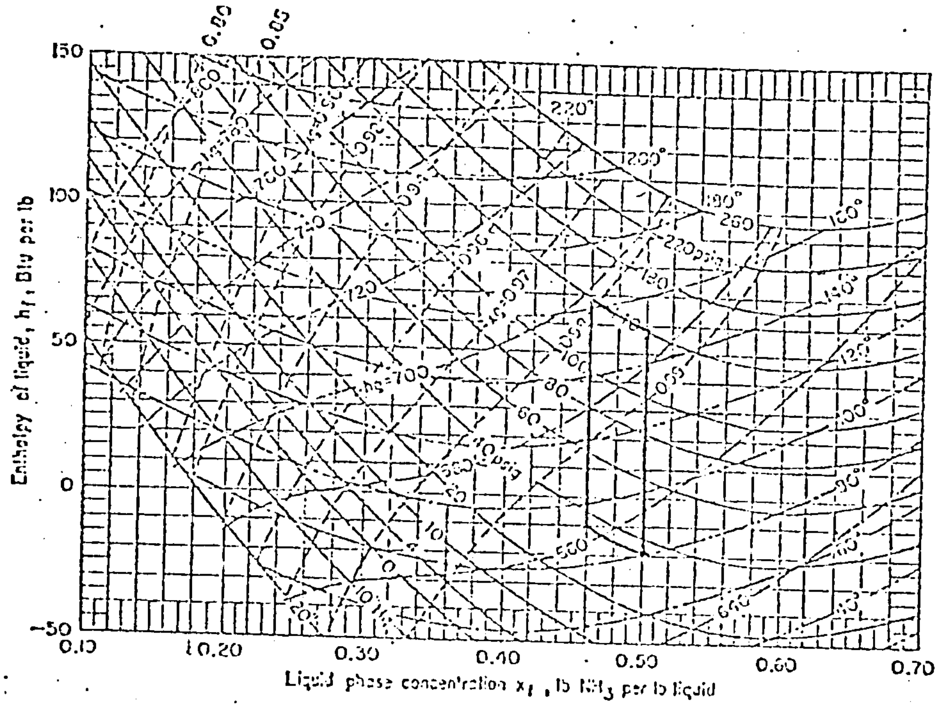
Generation (Charging) Mode





~~Fig.~~ Pressure-temperature relations of saturated vapors of refrigerants.

FIG. 2



. Physical properties of ammonia-water solutions.

FIG. 3

Source: Baumeister, T and L. S. Marks, Edit[illegible]
Standard Handbook for Mechanical Engi[illegible]
Seventh Edition, 1967
McGraw-Hill Book Company, New York

SECTION THROUGH SOLAR COLLECTOR AND CHARGING CONTAINER

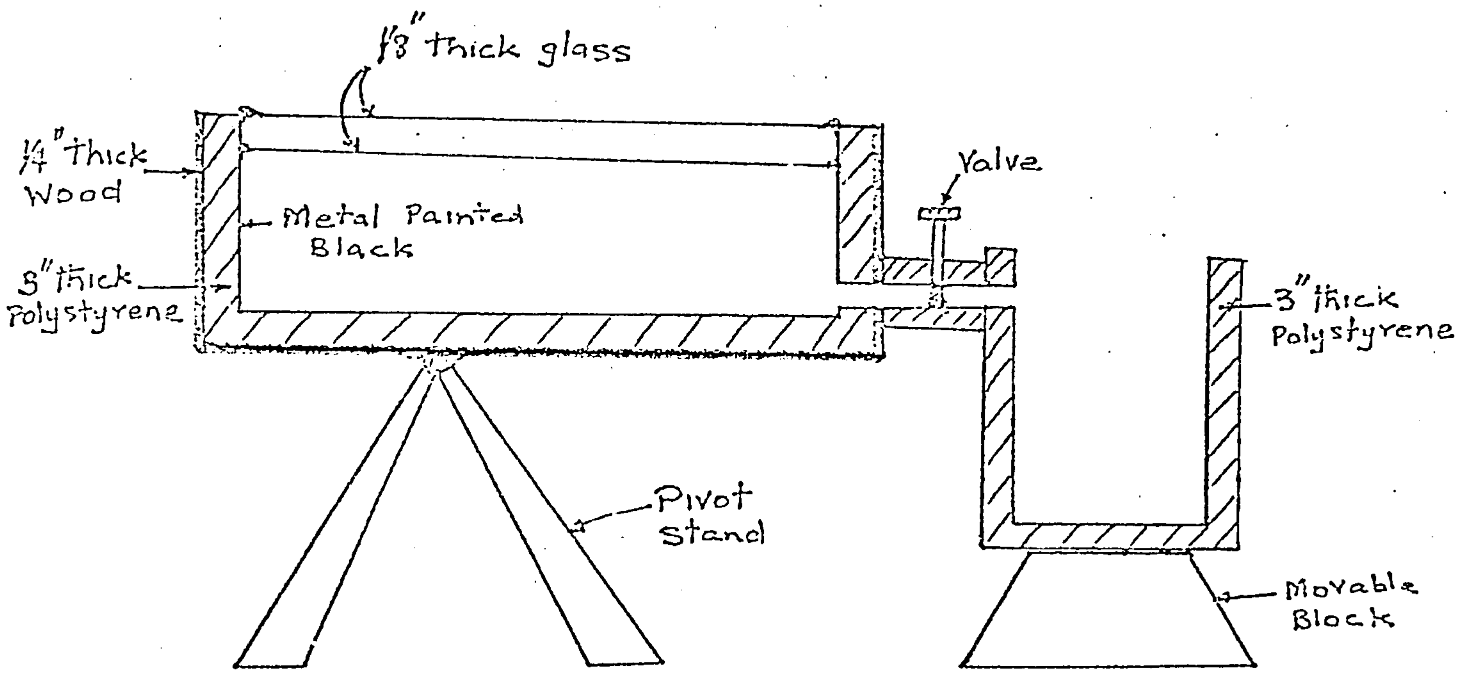


FIG. 4.

Design Calculations For an Ammonia-Water Intermittent Absorption Refrigeration System

Design Conditions and Parameters

1. (a) Temperature of heating water for generator = 165°F

   (b) Assuming a temperature difference (ΔT) of 5°F between Ammonia-water solution inside the generator and the heating water outside, temperature of Ammonia-water solution = 160°F.

2. (a) Temperature of cooling water for the condenser during the generation mode and the absorber during the cooling mode = 76°F

   (b) Assuming a temperature difference (ΔT) of 4°F between the cooling effect of the cooling water and the inside of the vessels, therefore cooling effect of circulating water = 80°F

3. (a) Temperature at which Ammonia vaporizes in the evaporator is taken as being = 20°F .

   (b) Assuming ΔT as 4°F between inside and outside of vessel, therefore, temperature of outside of vessel (Evaporator) = 24°F.

Generation Mode

In the generation mode (charging mode) the saturated vapour pressure ≡ saturated vapour pressure of ammonia at 80°F, using the pressure-temperature graph of Fig. 2 we find that the corresponding pressure is equal to 140 psig.

Cooling Mode

Saturated pressure at 20°F (Fig. 2) = 34 psig.

To Determine the Quantity of Ammonia-Water Solution

In the following calculations we will determine the amount of ammonia-water solution required to produce 2 lbs. of ice.

From the graph of Enthalpy vs Concentration (Fig. 3) the theoretical cycle is outlined.

Before the charging process begins, the concentration of the strong ammonia-water solution in the generator,

$$\text{i.e.} \quad \frac{\text{lb. } NH_3}{\text{lb. of solution}} = 0.50$$

After the charging process is completed the theoretical concentration of the weak solution that remains the generator, i.e.

$$\frac{\text{lb. of } NH_3}{\text{lb. of solution}} = 0.46$$

In the strong solution, for every pound of water the amount of ammonia required is given by

$$\frac{NH_3}{NH_3+1} = 0.50$$

$$NH_3 = 0.50\ (NH_3 + 1)$$

$$NH_3 = 1 \text{ lb.}$$

Therefore for every pound of water at this concentration 1 lb. of ammonia is required.

Since it is practically pure Ammonia which is evaporated during charging, every pound of water in the strong solution will be the same in the weak solution.

$$\text{Therefore} \quad \frac{NH_3}{NH_3+1} = 0.46$$

$$NH = 0.46\ (NH_3 + 1)$$

$$NH_3 = 0.85 \text{ lb.}$$

The amount of ammonia which is generated after a complete charge is

$$1.0 - 0,85 = 0.15 \text{ lb.}$$

We need to know the total refrigeration load to determine the amount of am
needed to be evaporated to produce the 2 lbs. of ice.

Refrigeration load required to cool the evaporator vessel

$= M \times C_p \times \Delta T$

$= 44 \times 0.1 \times (80-20)$

$= 264$ B.T.U.

Refrigeration load required to cool the refrigerant (NH_3) from 80^oF to 20^o

$= (132 - 64.7) \times M_{NH_3}$ (where M is the required lbs. of NH_3 to be ev

$= 67.3$ M B.T.U.

To make 1 lb. of ice $\equiv$ 144 B.T.U.

Therefore 2 lbs. of ice $\equiv$ 288 B.T.U.

Total refrigeration load $= 264 + 67.3M + 288$
$(522+67.3M)$B.T.U.

Refrigeration effect of 1 lb. of Ammonia = 500 B.T.U.

Therefore if the amount of Ammonia that has to be evaporated is M lbs, then

$$\frac{552+67.3M}{500} = M \text{ lb. of } NH_3$$

$$M = 1.28 \text{ lb.}$$

Amount of Solution $= \frac{2 \times 1.28}{0.15} = 17$ lb.

(0.15 lb. $NH_3 \equiv 2$ lb. solution)

Since the ratio of water to ammonia in strong solution = 1.1, to generate 1.28 lb of pure ammonia we need 8.5 lbs H_2O and 8.5 lbs of NH_3 in solution.

<u>To calculate dimensions of evaporator</u>

If we choose diameter of evaporator = 3 inches then

$$\frac{\pi D^2}{4} L = \text{Volume of } NH_3$$

Volume of saturated NH_3 liquid @ 80^oF = 1.28 x 0.0247 = 0.032 cu.ft.

$$\therefore L = \frac{4 \times 0.032}{\pi \times (3/12)^2} = 0.65 \text{ ft.}$$

Choose evaporator to be 1 ft. long providing a vapour allowance of 35%.

Since the working pressure is as high as 140 p.s.i. we need to determine what should the minimum thickness of the vessel be to withstand twice the working pressure, i.e. 280 p.s.i.

$$P \times D \times L = 2 \times E \times L \times S$$

where

P = Twice working pressure

D = Diameter of vessel

L = Length of vessel

E = Thickness of the Material

S = Tensile strength of Material (40,000 lb/in^2)

$$\therefore E = \frac{P \times D \times L}{2 \times L \times S} = \frac{PD}{2S} = \frac{280 \times (3/12)}{2 \times 40{,}000} = 0.011 \text{ inches.}$$

Therefore choosing standard available thickness of 0.25 inches is safe.

<u>To Determine the Dimensions of Generator</u>

Density of $NH_3 - H_2O$ solution in generator

$$= \rho_{H_2O} \times X_{H_2O} + \rho_{NH_3} \times X_{NH_3} = \rho_{H_2O} \times X_{H_2O} + \rho_{NH_3} \times X_{NH_3}$$

$$= 62.4 \times 0.5 + 37.48 \times 0.5$$

$$= 49.94 \text{ lb/cu.ft.}$$

Volume of solution $= \frac{17.0}{49.94} = 0.34$ cu.ft.

If we choose the diameter of the generator vessel to be 5 inches

$$\frac{\pi}{4} \times \left(\frac{5}{12}\right)^2 \times L = 0.34$$

$$L = 2.49 \text{ ft.}$$

Choose L = 2.5 ft. to allow for vapour space. Choosing standard thickness of 0.25 inches for generator is also safe.

Calculations to Determine the Size of the Solar Collector and the Charging Contair

Total heat required to raisethe temperature of the generator and ammonia-water solution to 160°F

$$= M_G \times C_{P_G} \times \Delta T_G + M_S (h_{fs} - h_{is}) + M_{NH_3} \times L_{NH_3}$$

$$= 88 \times 0.1 \times (160-80) + 16.5\{56-(-20)\} + 1.28 \times 498.7$$

$$= 704 + 1254 + 638.34$$

$$= 2596.3 \text{ B.T.U.}$$

If we assume a charging time of 1 hour the minimum surface area of the generator to transfer this amount of heat is given by

$$Q = U^1 A \Delta T t$$

$$A = \frac{2596.3}{200 \times 5 \times 1} = 2.6 \text{ ft}^2$$

check:

$$+ 2 \times \frac{\pi}{4} \times \left(\frac{5.5}{12}\right)^2$$

Surface area of generator $= \pi \times \frac{5.5}{12} \times 2.5 = 3.6 \text{ ft}^2$

Therefore for the calculated dimensions the surface area is adequate.

Minimum collection area of collector to provide say 2600 B.T.U.'s assuming

(a) double glaze glass cover each of transmissivity 0.85
(b) Solar Insolation of 300 B.T.U. ft^{-2}
(c) Efficiency of collector is 0.65
(d) Total insolation time per day of 6 hours

$$A = \frac{2600}{0.85 \times 0.85 \times 300 \times 0.65 \times 6} = 3.1 \text{ ft}^2$$

Mass of water required to produce 2,600 B.T.U. in 1 hour is given by

$$2600 = M \times C_p \times \Delta T \times t = M \times 1 \times (160-80) \times 1$$

$$M = \frac{2600}{80} = 32.5 \text{ lb.}$$

The volume of this water $= \frac{32.5}{62.4} \quad (\frac{M}{P})$

$$= 0.52 \text{ ft}^3$$

Although this is the minimum amount of ~~watts~~ water required, another limiting factor is the amount of water required to completely submerge the generator.

If we assume that the charging container is cylindrical and that when the generator is submerged it is surrounded by 2 inches of ~~watts~~ water on all sides and at the top and bottom, then

where:

$h \equiv$ height of water
$D_c \equiv$ Diameter of containe
$D_G \equiv$ Diameter of Generator

$$h = 2.5' + (4'/12) = 2.83 \text{ ft.}$$

$$D_c = D_G + (4/12')$$

$$= (\frac{5.5}{12}) + (\frac{4}{12}) = 0.79 \text{ ft.}$$

$$\text{Volume of water} = \frac{\pi}{4} \{D_c^2 - D_G^2\} \times 2.83 + \frac{4}{12} \times D_c^2 \times \frac{\pi}{4}$$

$$= \frac{\pi}{4} \{(0.79)^2 - (0.46)^2\} \times 2.83$$

$$= 0.92 \text{ ft}^3$$

The mass of this water $= 62.4 \times 0.92 = 57.5$ lb.

To calculate the actual surface area of this collector we have to first find Q,

$$Q = M \times C_p \times \Delta T$$

$$= 57.5 \times 1 \times (165-80)$$

$$= 4879 \text{ B.T.U./hr.}$$

Therefore area of collector $= \dfrac{4879}{0.85 \times 0.85 \times 300 \times 0.65 \times 6}$

5.8 ft^2

Choose the surface area of the collector to be 6 ft^2.

Dimensions are (a) length = 3 ft.

(b) width = 2 ft.

The thickness of water layer in the collector $= \dfrac{0.92}{5.8}$

= 0.16 ft or 1.9 inches (use 2" o

Thickness of collector = thickness of water layer

+ distance from water surface to 1st layer of glass

+ Separation of double layers of glass

+ 2 x thickness of glass

+ overlap of metal

= 2" + 1 1/2" + 1/2" + (2x1/8") + 1/4" respectively

= 4 1/2"

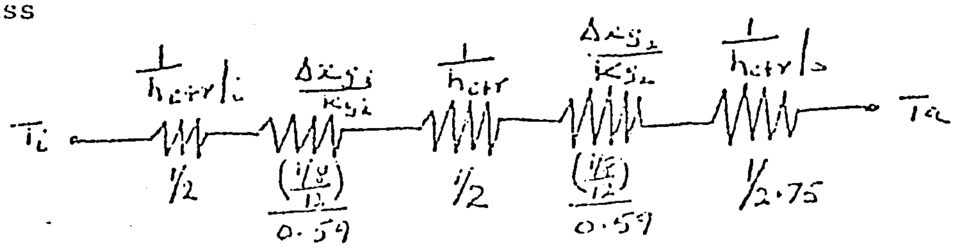
Heat Loss Analysis of Collector & Charging Vessel

To prevent heat losses both in the solar collector and the charging contain they are both insulated. The charging container is insulated with 3" thick poly styrene whereas the collector is surrounded at its sides and bottom with 3" thic polystyrene contained in a broad box 1/4" thick.

Assuming an ambient temperature of 85°F and an average wind speed of 5 m.p.! the losses from both the collector and the container is calculated.

(a) collector

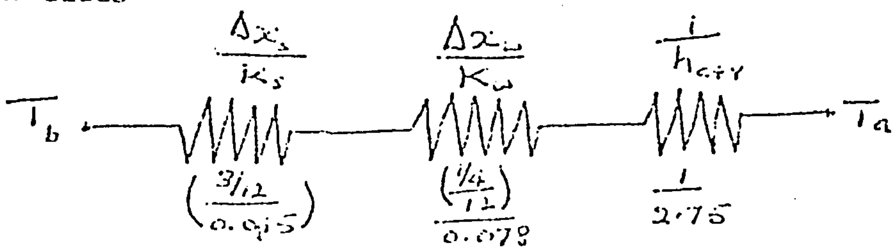
(i) Front glass



$$R_f = 0.5 + 0.018 + 0.5 + 0.018 + 0.364 = 1.4 \ \frac{ft^2 hr^oF}{B.T.U.}$$

$$U_f = \frac{1}{R_f} = 0.714 \ \frac{B.T.U.}{ft^2 hr^oF}$$

(ii) Bottom and sides



$$R_{b_1s} = 16.67 + 0.267 + 0.364$$

$$= 17.30 \ \frac{ft^2 hr^oF}{B.T.U.}$$

$$U_{b_1s} = 1/R = 0.058 \ \frac{B.T.U.}{ft^2 hr^oF}$$

heat loss from front of collector $= U_f A \Delta T$

$= 0.714 \times 3 \times 2 \times (165-85)$

$= 342.72$ B.T.U./hr

heat loss from sides & bottom $= U_{b_1s} A \Delta T$

$= 0.058 \times \{(3\times2)+2(3\times\frac{4\frac{1}{2}}{12})+2(2\times\frac{4\frac{1}{2}}{12})\}(165-85)$

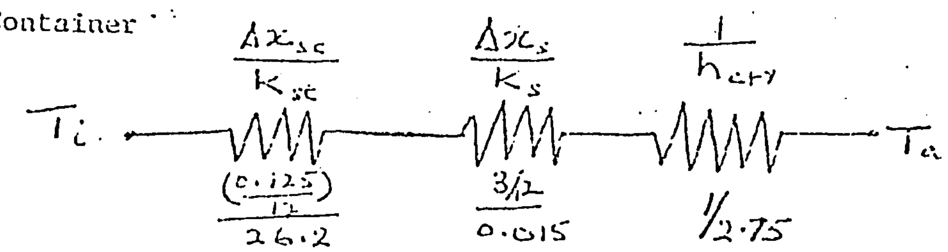
$= 0.058 \ \{6 + 2.25 + 1.5\} \times 80$

$= 0.058 \times 9.75 \times 80$

$= 45.24$ B.T.U./hr

Therefore total heat loss from collector $=$ 387.96 B.T.U./hr.

(b) Charging Container



$$R = 0.0004 + 16.67 + 0.364$$

$$= 17.03 \ \frac{ft^2 hr\,^oF}{B.T.U.}$$

$$U = 1/R = 0.059 \ \frac{B.T.U.}{ft^2 hr\,^oF}$$

$$\text{Heat loss} = U \times A_{ar} \times \Delta T$$

$$= 0.059 \times \pi \times D_{ar} \times L(165-85)$$

$$= 0.059 \times \pi \times 0.915 \times L \times 80$$

$$= 37.75 \text{ B.T.U./hr}$$

The total heat loss from the charging container and the solar collector

$$= (387.96 + 37.75) \text{ B.T.U./hr}$$

$$= 425.71 \text{ B.T.U./hr.}$$

Total heat supplied = 4870 B.T.U./hr

Total heat required = 2596.3 B.T.U./hr

Total heat loss = 425.71 B.T.U./hr.

When the ammonia is being generated from the generator during the charging mode, and the evaporator is performing its dual function as a condenser, the hot vapour has to be condensed at a reasonable rate. This is to prevent the onset of an equilibrium state before the maximum amount of ammonia is generated. Faili this the refrigeration effect will be less than the calculated requirement. To achieve the required rate of condensation the mass flow rate of the cooling water has to be calculated.

Amount of NH_3 evaporated $= 1.28$ lb.

Sensible heat contained in NH_3 to be given up to 80°F cooling water

$$\equiv (h_{160} - h_{80})1.28$$

$$= 1.28\ (699-661)\ \text{B.T.U.}$$

$$= 48.64\ \text{B.T.U.}$$

Latent heat in this $NH_3 = M \times L = 1.28 \times 498.7$ B.T.U.

$$= 638.34\ \text{B.T.U.}$$

Therefore the total B.T.U. that has to be removed by cooling water

$$= 48.64 + 638.34$$

$$= 686.98\ \text{B.T.U.}$$

The mass of water required to do this cooling is obtained from the following;

$$M \times C_p \times \Delta T = 686.98$$

$$M \times 1 \times (160-80) = 686.98$$

$$M = \frac{686.98}{80}$$

$$= 8.59\ \text{lb.}$$

Since the charging time is 1 hour the mass flow rate of the water should be a minimum of 8.59 lb/hr.

Similarly when the generator is performing its dual function as an absorber, the flow rate of the cooling water has to be determined so as to ensure that the weak ammonia-water solution will absorb the ammonia vapour as fast as it is given off from the evaporator. Failure to do so will result in little or no cooling effect.

We need to produce the ice in 1/2 hour.

Total heat required to be removed by the cooling water per hour

$$= \frac{M_C \times C_{P_C} \times \Delta T_C + M_{NH_3}\ L_{NH_3} + \text{temp. to cool the ammonia to } 80^\circ F}{1/2}$$

CONCLUSIONS

The future of solar refrigeration and air conditioning seems to be a very good proposition and no doubt will find its place in future industrial applications. The major limiting factor at present is the shape of energy so as to make it available whenever it is required, for example at nights and extended cloudy days when we cannot attain a high enough temperature. In the case of air conditioning and refrigeration, storage can either be done in the form of heat or as the final product (cold water or ice). The latter is a much easier form of storage but it is rather bulky, for this reason there has been ongoing research in the area of storage in various forms, trying to make use of phase change materials, Eutectics, oils, etc., which has the potential of storing large quantities of energy within a small space and over a longer period of time than water. With the achievement already made in this field, the technology will no doubt be available for large scale application in the near future. Coupled with a more elaborate design of the refrigeration system that we have designed we could go a far way in supplementing solar energy for the conventional energy used for these processes today.

The temperature to cool the ammonia is very small and can be neglected.

$\therefore$ total heat to be removed/hour

$$= \frac{M_G x C_{P_G} x \Delta T_G + M_{NH_3} L_{NH_3}}{1/2}$$

$$= \frac{88 x 0.1 x (85-80) + 1.28 x 500}{1/2}$$

$= 1368$ B.T.U./hr.

This is on the assumption that all the ammonia is evaporated in the evaporator and that the generator vessel had reached equilibrium temperature with the ambient temperature (85°F).

Therefore mass flow rate of water $= \frac{1368}{80}$

$= 17.1$ lb/hr.

In the remote villages it is hardly likely that running water will be availab therefore all that is required is to put the vessel to be cooled into a basin of water at least twice the weight of running water per hour. This is to compensate for the fact that the stagnant cooling water will increase in temperature with tim

Coefficient of Performance (COP)

The maximum theoretical COP that can be obtained from this system operating between the three temperatures T_h, T_s, & T_c

$$= \frac{T_c(T_h - T_s)}{T_h(T_s - T_c)}$$

$$= \frac{20(165-76)}{165(76-20)}$$

$= 0.3$

where

T_h ≡ Temperature of generating hot water

T_s ≡ Temperature of the cooling water

T_c ≡ Refrigeration temperature.